PHYSICAL AND CHEMICAL SOIL ATTRIBUTES IN AREAS SUBJECTED TO REFORESTATION, COMPARED TO NATIVE FOREST AND DEGRADED PASTURE, IN THE BRAZILIAN AMAZON

José Augusto Amorim Silva do Sacramento[1], Adriele Rachor Taglieber[2], João Carlos Moreira Pompeu[3]; Milton Sousa Filho[4], Arystides Resende Silva[5], Emerson Cristi de Barros[6]

RESUMO – O rápido crescimento da agricultura, promovido por iniciativas públicas, favoreceu um desmatamento descontrolado, de forma que hoje é necessário utilizar alternativas sustentáveis de melhoramento e conservação do solo. Nesse contexto, o presente estudo teve como objetivo avaliar comparativamente, com a mata nativa, os atributos físicos e químicos, em áreas com diferentes épocas de reflorestamento, no planalto, Santarém, Pará, Brasil. A pesquisa foi desenvolvida em cinco áreas, a saber: área de reflorestamento com oito anos (AR8), área de reflorestamento com sete anos (AR7), área de reflorestamento com seis anos (AR6), área de pastagem degradada (APD) e fragmento de mata nativa (FMN). As amostras de solo deformadas e indeformadas foram coletadas nas profundidades de 0,00 - 0,05 m; 0,05 - 0,10 me 0,10 - 0,20 m, com oito repetições por área e um total de 120 amostras deformadas e 120 indeformadas. Foram avaliados os atributos químicos (P, K^+, Na^+, Ca^{2+} Mg^{2+}, H^++Al^{3+}, CTC efetivo, pH, saturação por bases, saturação por alumínio e matéria orgânica) e físico do solo (densidade do solo, densidade de partículas e porosidade total). As áreas de reflorestamento AR8 e AR7 apresentaram resultados estatisticamente iguais aos da FMN para atributos físicos, densidade e porosidade total do solo. AR6 e APD obtiveram maior compactação na camada de 0,0-0,5 m. A FMN, por sua vez, apresentou baixa CTC e alto índice de acidez, provavelmente devido à intensa deposição e decomposição da serapilheira em sua superfície. As condições do solo no reflorestamento aos oito e sete anos, demonstram que após esse período, houve uma melhoria, principalmente nos atributos físicos do solo (densidade e porosidade total), com valores que se igualam às condições naturais. O período de seis anos não foi suficiente para recuperar a densidade e porosidade total do solo. As áreas de reflorestamento AR8 e AR7 elevaram a fertilidade do solo com valores de V acima de 50% na camada superficial do solo.

Palavras-chave: Pastagem degradada, reflorestamento, atributos físicos e químicos do solo.

SOIL PHYSICAL AND CHEMICAL QUALITY IN REFORESTATION AREAS, IN AMAZON, BRAZIL.

ABSTRACT *– The rapid growth of agriculture, promoted by public initiatives, favored uncontrolled deforestation, so today it is necessary to use sustainable alternatives for soil improvement and conservation. In this context, the present study aimed to comparatively evaluate, with the native forest, the physical and chemical attributes, in areas with different periods of reforestation, in the plateau, Santarém, Pará, Brazil. The research was carried out in five areas, namely: eight-year-old reforestation area (AR8), seven-year-old reforestation area (AR7), six-year-old reforestation area (AR6), degraded pasture area (APD), and a fragment of native forest (FFN). Deformed and undisturbed soil samples were collected at depths of 0.00 - 0.05 m; 0.05 - 0.10 m and 0.10 - 0.20 m, with eight repetitions per area and a total of 120 deformed and 120*

[1] Doutor, Professor do Instituto de Biodiversidade e Florestas, (IBEF)/UFOPA). E-mail: jassacramento@yahoo.com.br
[2] Engenheira Florestal, Instituto de Biodiversidade e Florestas/UFOPA. E-mail: adriele.taglieber@gmail.com
[3] Engenheiro Florestal, Instituto de Biodiversidade e Florestas/UFOPA, mestrando da Universidade Federal do Amazonas. E-mail: pompeu.joao123@gmail.com
[4] Engenheiro Florestal, Instituto de Biodiversidade e Florestas/UFOPA. msfsgt@hotmail.com
[5] Pesquisador da Embrapa Amazônia Oriental, Belém-Pará. E-mail: arystides.silva@embrapa.br
[6] Doutor, Professor do Departamento de Engenharia Agrícola, Universidade Federal de Viçosa. E-mail: emerson.barros@ufv.br

undisturbed samples. Chemical (P, K+, Na+, Ca2+ Mg2+, H++Al3+, effective CEC, pH, base saturation, aluminum saturation, and organic matter) and physical attributes of the soil (soil density, particle density, and porosity) were evaluated. total). Reforestation areas AR8 and AR7 presented results statistically similar to those of FFN for physical attributes, density, and total soil porosity. AR6 and APD achieved greater compaction in the 0.0-0.5 m layer. FMN, in turn, showed low CEC and high acidity, probably due to the intense deposition and decomposition of the litter on its surface. The soil conditions in the reforestation at eight and seven years show that after this period, there was an improvement, mainly in the physical attributes of the soil (density and total porosity), with values that are equal to the natural conditions. The period of six years was not enough to recover the total density and porosity of the soil. Reforestation areas AR8 and AR7 increased soil fertility with V values above 50% in the topsoil layer.

Keywords: Degraded pasture, reforestation, physical and chemical soil attributes.

INTRODUCTION

The indiscriminate suppression of forest vegetation, as well as the inadequate use and management of natural resources, have caused, among other problems, soil degradation. This degradation causes a decrease in the natural fertility of the soil and in the levels of organic carbon, which alters its structure and composition (Silva & Curi, 2001).

With this, the environmental consequences related to the soil degradation process, such as the decline of organic matter, compaction, loss of soil biodiversity, and nutrient depletion, will make them less productive, harming their functions within the environment (Constantini & Lorenzetti, 2013).

The increasing deforestation of the Amazon Forest emerges as one of the main problems for the conservation of edaphic characteristics related to the maintenance of soil quality within the forest environment, since the loss of biodiversity, the rapid decline in fertility, and the alteration of properties of soil physical and chemical properties are considered important examples of the consequences of deforestation (Poça, 2012; Kassa et al., 2017; Franco et al., 2018).

In addition, this situation can worsen when considering that new areas continue to be deforested for the expansion of agricultural activities since such activities contribute to reducing the chemical, physical and biological quality of the soil (Rosendo & Rosa, 2012). Among the physical properties of the soil, which are hierarchically most important, the following stand out: texture and structure, in which the first refers to the distribution of particles and the second reference to the arrangement of particles in the aggregates (Reinert & Reichert, 2006). The authors also point out that porosity is also an important attribute, as it is responsible for a set of phenomena that develop a series of essential mechanisms in soil physics, such as retention and flow of water and air.

Soil chemical properties can also be considered quite responsive variables about soil quality after the degradation process, since the soil is one of the most efficient carbon stocks, being able to store up to three times more carbon in soil compared to vegetation, however, the largest fraction of the nutrient is in organic form, present in organic matter, which makes it very vulnerable to any form of improper soil management. (Cantarella, 2007; Cerri & Cerri, 2007).

While the limitation of nutrients present in Amazonian soils is a major challenge for more efficient decision-making for the correct use of soil management in areas subject to reforestation. Given this, one of the main roles of reforestation is to minimize the effects of deforestation, especially on the surface layer of the soil, which, even though it takes a long period, still, this practice is advantageous due to the numerous ecological benefits arising from it the correct use of organic soil management resulting from reforestation (Veldkamp et al, 2020).

Thus, the importance of adopting good agricultural practices is observed, such as no-till, reforestation the use of practices that integrate the forest, livestock agriculture. In this context, two questions arise and guide this work: first, how does the removal of vegetation cover alter the quality of the soil, under physical and chemical attributes? Second, to what extent can revegetation improve physical and chemical characteristics in degraded areas?

Aiming at this problem, the present work hypothesized that reforestation with forest species contributes to the improvement of soil quality under physical and chemical attributes. This work was carried out to evaluate soil quality in reforestation areas in the Amazon region at different ages, using physical and chemical soil indicators.

MATERIAL AND METHODS

Characterization of the study area

The study was carried out at Fazenda Diamantino located in the municipality of Santarém - PA, at km 11 of the Santarém - Curuá-Una highway (PA 370), between coordinates 54 ° 39 ‘44.622” W and 2 ° 30’38.409” S (Figure 1). The region’s climate follows the Ami standard, hot and humid, according to the Köppen classification, and is characterized by an annual average temperature of 25.9 ° C and relative humidity of 86% (Silva and Sablayrolles, 2009). The municipality’s soil is classified as a typical Latossolo Amarelo Distrófico A moderate, very clayey texture, with flat and smooth wavy relief (Rocha, 2014). The vegetation in the municipality of Santarém is characterized by very distinct forest formations: subperenifolian equatorial forest and subperenefolium equatorial savannah, on the mainland (Embrapa, 2001).

The study area, however, is characterized by subperenifolia equatorial forest, which is represented by floristic types where evergreen species predominate, but with slightly reduced foliage in the dry season, due to leaf loss strategies. Trees of up to 50 meters in height or more can occur, with an understory rich in palm trees (Embrapa, 2001).

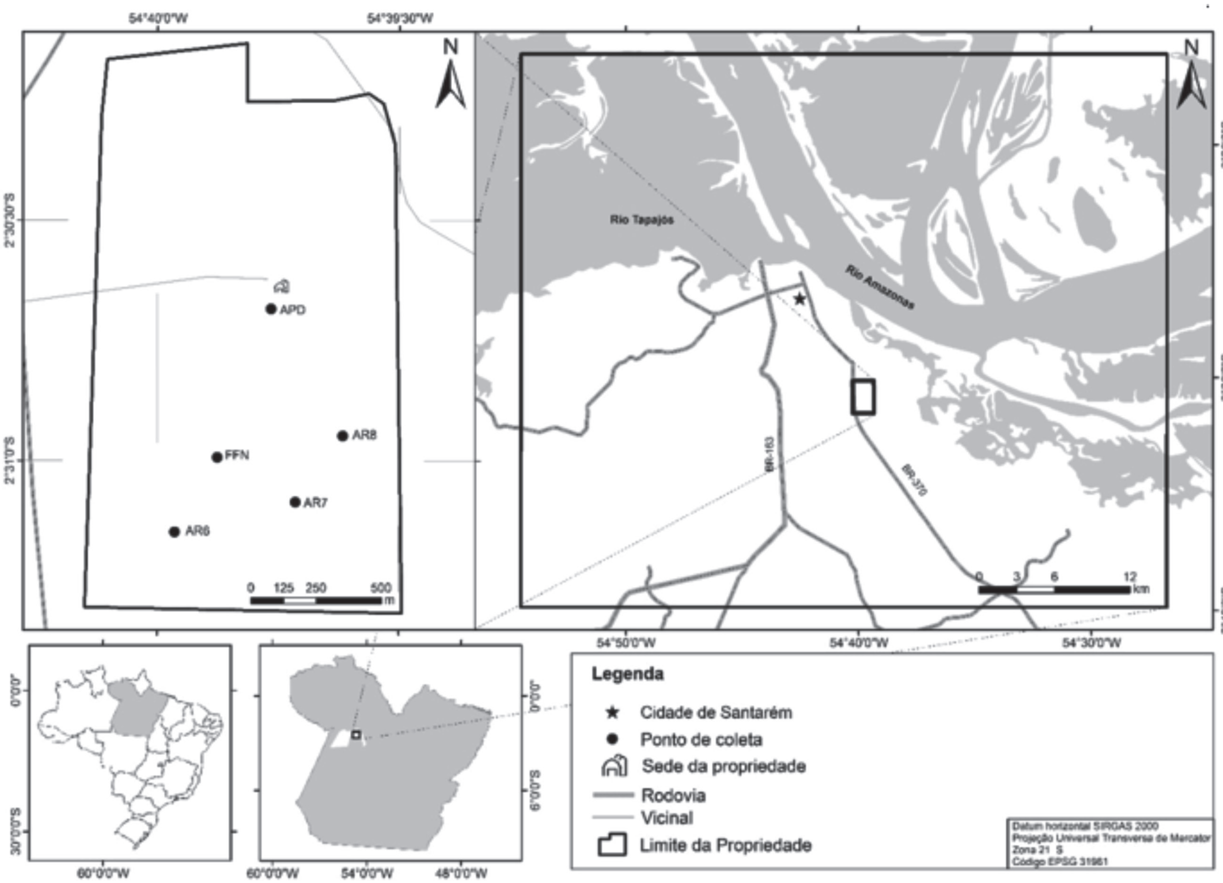

Figure 1 - Location of the experimental area, Diamantino farm, Santarém, Pará, Brazil.

The property has a total area of 240 ha, of which 127.66 ha (about 53%) were destined for monoculture activities of grains such as corn and soybeans and extensive livestock, with cattle raising and milk production. These activities were practiced for a long time, a fact that contributed to the degradation of the area. However, to try to reverse this situation, a reforestation project was carried out on the property by planting forest species such as andiroba (Carapa guianensis), cumaru (Dipteryx odorata), neem (Azadirachta indica), Brazilian mahogany (Swietenia macrophylla), and yellow ipe (Handroanthus serratifolius), with ecological, environmental and economic interests (Souza et al., 2006; Carvalho, 2007).

For the implementation of the project, the area was, and went through a mechanization process to prepare the land. The fertilization in the pit was carried out with organic fertilizer composed of chicken beds and bovine manure. Each field was installed in a different year, with field 1 in 2008, field 2 in 2009 field 3 in 2010. For the present study, the three plots called AR8, AR7, AR6 were analyzed, which were compared with a fragment of preserved native forest (FFN), and a degraded pasture area (APD). Below is a detailed description of each area used for the development of the research:

Eight-year-old reforestation area (AR8) - was implemented in 2008, in an area of 24.53 ha and has a total of 5,000 individuals among andiroba, cumaru, yellow ipe, mahogany neem, in a 7x7 m spacing. The soil in this area has a texture that varies from silty clay in the most superficial layer (0.00-0.05 m) to very clayey in the deepest layer (0.10-0.20 m).

The reforestation area with seven years (AR7) - implanted in 2009 and 31.78 ha, has a total of 6,400 individuals of the species andiroba, neem, yellow ipe, cumaru mahogany in of 7x7 m. Planting was carried out in pits with dimensions of 50x50x50 cm. The texture of the soil in that area varied from silty clay loam in the superficial layer (0.00-0.10 m) to very clayey for the greatest depth (0.10-0.20 m).

Six-year-old reforestation area (AR6) - inserted in 2010, with a size of 26.12 ha and 5,300 individuals, the species present are mahogany, yellow ipe, andiroba, cumaru in the 7x7 m spacing. Neem, being an exotic species and showing invasive behavior, was replaced by mahogany seedlings, as it has a greater economic and ecological value. AR6 presented a soil with a clay texture throughout the verified layer.

Degraded pasture area (APD) - has compacted soil with the presence of invasive species. This area is close to the farm's headquarters and was a place for cattle grazing. It went through liming to correct acidity and intense chemical fertilizer applications for grass production and the intense traffic and densification of animals. The APD presents the largest amount of sand among all the studied areas, with a frank texture in the first 5 cm of soil thickness, which varied to clay loam due to the increase in clay with depth.

Fragment of native forest (FFN) - The witness consists of a fragment of native forest that is very conserved, with an enormous richness of species, composed of individuals that can reach up to 30 m in height. This area is equivalent to the property's Legal Reserve, which has a little more than 100 ha, corresponding to 50% of the total area of the property. The soil texture of the FFN is characterized by the increase of clay with increased depth, with varied from clay to very clayey.

The contents of coarse sand, fine sand, clay, silt, as well as the textural classification of all areas and their respective sampled depths, can be seen in table 1.

Table 1 - Particle size and textural class at depths of 0.0-0.05 m; 0.05-0.10 m and 0.10-0.20 m from the Diamantino Farm, Santarém, Pará.

		Granulometry (g kg^{-1})			
Study areas	Depth (m)	Total Sand	Total Clay	Silte	Texture*
	0.0-0.05	150	340	510	CSCT
AR8	0.05-0.10	150	480	370	SCT
	0.10-0.20	114	620	266	VCT
	0.0-0.05	158	340	502	CSCT
AR7	0.05-0.10	132	340	528	CSCT
	0.10-0.20	111	680	209	VCT
	0.0-0.05	195	420	385	CT
AR6	0.05-0.10	170	580	250	VCT
	0.10-0.20	150	640	210	VCT
	0.0-0.05	296	260	444	FT
AP D	0.05-0.10	393	300	307	CLT
	0.10-0.20	393	340	267	CLT
	0.0-0.05	180	540	280	CT
FF N	0.05-0.10	138	640	222	VCT
	0.10-0.20	124	620	256	VCT

*CSCT: Clay silty clay texture; SCT: Silty clay texture; VCT: Very clayey texture; CT: Clay texture; FT: Frank texture; CLT: Clay loam texture.

It is worth mentioning that the reforestation areas, during the winter, became temporary silvopastoral, since they are rented for cattle grazing.

Collection, processing analysis of soil samples.

Initially, since the areas have large dimensions, a plot was demarcated in each area with a size of about one hectare for the collection of soil samples, which were carried out at random within each demarcated plot.

The collections of deformed and undisturbed soil samples were carried out at the depths 0.00 - 0.05 m: 0.05 - 0.10 m and 0.10 - 0.20 m, with 8 repetitions per area, totaling 120 deformed samples and 120 undisturbed samples. The undisturbed samples were collected with the aid of a 98.4 m^3 volumetric ring and the deformed samples, through the opening of mini trenches.

The deformed samples went through the air-drying process, for a period of more or less 24 hours and later were sieved in a sieve with a mesh of 2.0 mm in diameter, to obtain the air-dried fine soil (TFSA).

Among the physical soil properties, it was given bulk density, particle density, particle size porosity total as co-methods compilations and described in Teixeira et al. (2017). Total porosity (Pt) was calculated by the relationship between the density of the soil (Ds) and the density of particles (Dp), according to the equation:

$$Pt = [1- (Ds / Dp)] \times 100$$

Where: Pt = Total porosity (%); Ds = Density of the soil (g cm^{-3}) and Dp = Density of particles (g cm^{-3})

Chemical analyzes of pH (H_2O), P, K^+, Na^+, Ca^{2+}, Mg^{2+}, Al^{3+}, ($H^+ + Al^{+3}$) were performed at the Soil Laboratory of Embrapa Amazônia Oriental, in Belém, PA. The base sauration (BS) and the cation exchange capacity (CEC) at pH 7.0 were obtained respectively by the following expressions: $BS = Ca^{2+}+Mg^{2+}+Na^{+}+K^{+}$; $CEC = BS+ (H^{+}+Al^{+3})$; $V\% = (CEC/BS) \times 100$ e $m\% = (Al^{+3}/ (BS+ Al^{+3}))\times 100$ (Teixeira et al., 2017).

Experimental design and statistical analysis of the data

The design used was the DIC (completely randomized design) with five treatments and eight repetitions. The Shapiro-Wilk normality test was applied and as the data did not show normal, even after processing, non-parametric statistics were performed with the Kruskal-Wallis test at 5% probability. The statistical analysis was performed using the ASSISTAT 7.7 statistical software (Silva & Azevedo, 2016).

RESULTS AND DISCUSSION

Physical Soil Quality

For bulk density, there is a significant difference between the areas compared to the 5% probability level.

FF area C showed the lowest average for the bulk density at the three depths (from 0.00 to 0.05, 0.05-0.10, and 0.10-0.20 m) sin of 0.87 Mg m^{-3}, 0.91 Mg $m^{-3,}$ and 0.94 Mg m^{-3}, respectively. The APD consequently obtained the highest values for the Ds among the depths analyzed, with values of 1.36 Mg m^{-3}, 1.28 Mg $m^{-3,}$ and 1.31 Mg m^{-3} (Figure 2). Loss et al. (2011), when comparing an area of Cerrado, which did not undergo anthropic intervention, with areas under no-tillage, concluded that the management carried out in these areas, probably contributed to soil compaction.

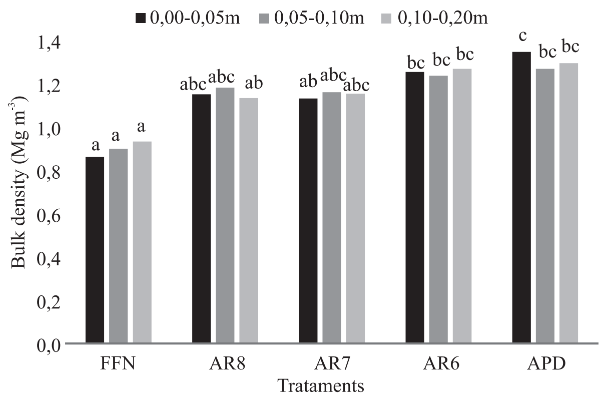

Figure 2 - Valores average bulk density of soil (mg m^{-3}) in dystrophic Yellow clayey in reforestation area with eight years (AR8), reforestation area co m seven years (AR7), reforestation area aged six (AR6), degraded pasture area (APD) and a fragment of native forest (FFN), at different depths, Santarém-PA.

* Averages followed by the same letters do not differ statistically by the Kruskal-Wallis test at the level of 5% probability for the depths studied.

At the depths evaluated, the ar and FF N only differed statistically from APD and AR6. AR6 and APD, in turn, were statistically equal, concerning Ds, thus demonstrating that the reforested area at six years old is in a late stage of recovery.

At depth 0.00 -0.05 m, the density of the soil is statistically equal in the areas FFN, AR8, and A R7 (Figure 3), proving that the implanted species are fulfilling their role for soil restoration, probably due to the great deposition of litter, mainly in the most superficial layers of the soil. Fernandes et al. (2006), when studying the decomposition and litter contribution of two species in a secondary forest area, found that, among the studied species, *Carapa guianensis* presented the highest performance in litter deposition, with values reaching 9.20 Mg ha^{-1} year.

In depths 0.05-0.10 and 0.10-0.20 m, compared, the areas AR8, AR7, AR6, APD showed no significant difference. However, the AP D at the depth of 0.00-0.05 m shows a significant difference when compared to the AR7 at the same depth, a fact that can be explained by the high degree of compaction of the topsoil of the degraded pasture area.

Note that in AP D, depths 0, 0-0.05, and 0.10-0.20 m showed density values above those considered critical for clay soils, which are between 1.30 and 1.40 g cm^{-3} (Reichert, 2003). Similar results were found by Stone et al. (2015), in silviagricultural systems, were among the tree planting lines, which had cover plants the values of Ds. were close to the upper limit, while in the tree lines the values of Ds. were below critical values. The author explains that these results are since in the vicinity of the trees there is a deposition of litter, which contributes to improving the physical attributes of the soil.

It is also noted that in FFN and AR7, the density of the soil increases with depth, this is due to the decrease in the content of organic matter and the weight of the overlying soil layers. On the other hand, in AP D, there was a decrease in density with depth, since cattle trampling causes, mainly, the compaction of the most superficial layers of the soil. Assis et al. (2015) reported that because the trampling of cattle occurs in the soil surface between 0 and 0.10 m facilitates actions to restore the precondition ground by natural agents.

There was no significant difference between treatments between FFN, AR8, and AR7. The FF does not differ statistically, only from APD and AR6 (Figure 4).

The FF N showed the highest values of total porosity with 64.95%, 63.38%, and 63.37% at depths 0.00-0.05; 0.05-0.10 and 0.10-0.20 m respectively, followed by AR7 with 5 4.46%, 54.72%, and 55.45% (Figure 3). These high porosity values are associated with the clayey texture of the soil in the FF N, contributing to the retention of water and nutrients, favoring the greater development of the species that occur in the area (Giácomo et al., 2015). According to Araújo et al. (2004), the porosity follows an inverse order of density, thus, in the FFN, there is a more porous soil, probably because it is a little disturbing environment and more protected from the weather (sun, rain, wind).

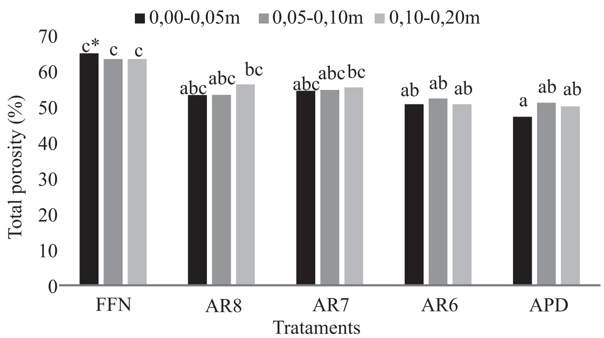

Figure 3 - Average values of soil porosity in (%) in an Oxisol with a clayey texture under an eight-year-old reforestation area (AR8), a seven-year-old reforestation area (AR7), a six-year-old reforestation area (AR6), an area degraded pasture (APD), and a fragment of native forest (FFN), at different depths, Santarém-PA.

* Averages followed by the same letters do not differ statistically by the Kruskal-Wallis test at the level of 5% probability for the depths studied.

Porosity showed higher values in the FFN, AR8, and AR7 areas, coinciding in environments with higher levels of organic matter, in agreement with the results of Camp os et al. (2010) and Martins et al. (2006). Alonso et al. (2015) explain that deciduous species, as in the case of yellow ipe, show leaf deposition peaks that increase litter supply in the soil. This accentuated leaf deposition is part of these species' strategies to reduce water losses due to evapotranspiration during the driest periods of the year.

It is noted that among all areas, porosity increases with depth, except in FFN, a decrease in porosity occurs at greater depths. This fact can be explained by the use of agricultural mechanization and trampling of cattle in the areas, which contributed to the compaction of the most superficial layers of the soil, in contrast to what is observed in the FF N, which suffered little anthropic intervention and has a greater quantity of individuals who contribute to an intense supply of organic matter to the soil, contributing to greater porosity, especially in the most superficial layer.

Soil Chemical Quality

The results for the phosphorus analysis of the areas showed that AP D and FF N have the highest phosphorus values among the treatments, with 47.0 mg dm^{-3}, 51.3 mg $dm^{-3,}$ and 49.1 mg dm^{-3} for the degraded area and 25.3 mg dm^{-3}, 21.8 mg dm^{-3} and 20.6 mg dm^{-3} for the native forest area at depths 0.00-0.05; 0.05-0.10 and 0.10-0.20 m respectively (Table 1). According to Brasil and Cravo (2020), the levels of phosphorus for AP D are classified as high and for FF N the values are considered average for soils in the State of Pará. These results are since the area of degraded pasture underwent soil correction and fertilization for grass production. Baldotto et al. (2015), also observed higher P^+ values for pasture areas, when compared to native forest and eucalyptus planting.

The AR6, in turn, had the lowest values of phosphorus, 9.9 mg dm^{-3} , 6.7 mg dm^{-3} and 4.8 mg dm^{-3} , followed by 10.8 mg dm^{-3} , 6.6 mg dm^{-3} and 4.3 mg dm^{-3} , at depths 0.00-0.05; 0.05-0.10 and 0.10-0.20 m respectively.

The mean values of phosphorus differed statistically only between APD and the depths 0.05-0.10 and 0.1 0-0.20 m in areas AR8, AR7, and AR6. FF N only showed a significant difference in the deepest layers of soil 0.10-0.20 m in AR8, AR7, and AR6 at the level of 5% probability.

In all areas, a pattern of decreasing P^+ stock is observed with increasing depth. However, Magalhães et al. (2013) found an increase in P^+ in depth when analyzing reforestation plantations with 5 years of age.

Table 1. Average values of chemical properties in Oxisol A yellow clay texture under eight-year reforestation area (AR8), seven-year reforestation area (AR7), six-year reforestation area (AR6), degraded pasture area (APD), and a fragment of native forest (FFN), at different depths, Santarém-PA. * Means followed by the same letters do not differ statistically by the Kruskal-Wallis test at the level of 5% probability for the depths studied.

K^+ values varied considerably between treatments. The lowest values were found in the native forest area of 37.3 mg dm^{-3}, 27.0 mg $dm^{-3,}$ and 15.6 mg dm^{-3} and the highest values are present in AP D with 265.8 mg dm^{-3}, 84. mg dm^{-3} and 62.2 mg dm^{-3} , respectively at the depths studied (0.00-0.05, 0.05-0.10 and 0.10-0.20 m) (Table 1). This very high value of K^+ in the top layer of soil in APD may be related to the application of fertilizers composed by K^+ in its formula.

The areas AR8, AR7, and AR6 present average values of K^+ in their most superficial layers of the soil, which suffer a decrease with the depth passing to low levels of K^+. This supply of K^+ in the reforested areas comes from the use of manure to fertilize the areas, according to Botelho et al. (2020), manure is a good supplier of nutrients, with all K^+ and P almost as available as other sources of mineral fertilizer. The FFN has K^+ values considered low, for the soils of the State of Pará, throughout the sampled soil depth (Brasil & Cravo, 2020). The authors also point out that Amazonian soils are naturally acidic and have a low amount of bases and high aluminum content, which explains the low K^+ values for a native forest.

Concerning K^+, statistical differences are found in the depth of 0.10-0.20 m between the areas FFN and APD.

The FF N showed very low base values (Ca^{2+} + Mg^{2+}) (Brasil & Cravo, 2020), characterizing typically Amazonian soils, which have a low amount of bases. In general, all areas have average values of Ca^{2+} + Mg^{2+}, except for the depth 0.0-0.05 m in areas AP D and AR8. The average values of the areas are by following results obtained by Rocha et al. (2015) when evaluating chemical attributes in reforestation areas of different ages.

These very low values of Ca^{2+} +Mg^{2+} must be associated with high concentrations of $Al3^+$ in the soil of FF N, which acts as an antagonist in the absorption process of these nutrients (Fragoso, 2016).

At depths 1 and 2, FF N differed statistically from AR8, AR7, AR6, and APD, except for AR6 at depth 1. However, at depth 3, there was only a difference between FF N and APD (Table 1).

Concerning the content of Na^+, there was no statistical difference between the analyzed areas are (Table 1).

The pH varied between the areas with values between 4.1 and 5.6. The highest value (5.6) was observed in AR9 and the lowest value (4.1) in FMN (Table 1). The lowest pH values for the native forest area are related to the natural acidity of the region's soils and the process of degradation of organic matter and its rapid mineralization. Júnior et al. (2012) also obtained low pH values (3.9 to 4.0) when analyzing the soils of native forest and agroforestry systems in the State of Pará.

For pH values, the FMN and AR7 areas did not differ statistically. The statistical differences were due to AR9 and FMN. The depth 0.00-0.05 m of AP D and the depths 0.00-0.05 m and 0.05-0.10 m of the AR8 also showed differences and statistics when compared.

The degraded pasture area showed values of pH 5.4; 5.2 and 5.0 respectively at depths 0.00-0.05; 0.05-0.10 m and 0.10-0, 20 m. These higher pH values, about to the

FMN, must be associated with liming processes carried out to correct the acidity of the soil for the production of grass for cattle.

Potential acidity ($H^{+} + Al^{3+}$) was higher in FFN, especially in the 0.00-0.05 m layer, (15.1 $cmol_c\ dm^{-3}$), which differed statistically from APD, AR8, and AR7.

There is a pattern of increased potential acidity in-depth for the areas, except for FFN, where the acidity decreases in the deeper layers, this is due to the fact of using organic fertilizers in the reforestation areas, which guaranteed the decrease of acidity in the topsoil of the soil, in the FFN, the acidity in the soil surface is due to the decomposition of organic matter resulting from the intense supply of litter in the area.

The FF N showed the lowest values of active acidity (pH) and highest values of potential acidity ($H^{+} + Al^{3+}$), results also observed by Cálgaro et al. (2015) in the area with the greatest cation exchange capacity at a depth of 0.0-0.05 m was AP D, with 7.4 $cmol_c\ dm^{-3}$ followed by AR8 with 6.8 $cmol_c\ dm^{-3}$ (Table 1). In the 0.05-0.10 m depth, the highest CEC was due to AR8 and later by APD with 5.3 $cmol_c\ dm^{-3}$ and 5.0 $cmol_c\ dm^{-3}$, respectively. The FF N showed the lowest values (3.4; 3.2 and 2.9 $cmol_c\ dm^{-3}$). Mello et al. (2009) also obtained lower results for forest CEC when compared to agricultural cultivation areas in the Amazon.

In general, the reforestation areas reached CEC between 3 and 6 $cmol_c\ dm^{-3}$, Júnior et al. (2012) and Rocha et al. (2015), obtained similar results in studies of agroforestry systems and reforestation with native species, respectively.

Regarding base saturation (V%) and aluminum saturation (m), the areas AR8, AR7, AR6, and AP D did not differ in the 0.0-0.05 m layer. In the 0.05-0.10 m layer, the FF N differed from AP D and AR8, and in the 0.10-0.20 m layer, AP D only differed from the FF N in the values of m (%).

The reforestation areas studied, in general, presented V values between 35 and 50%, values that corroborate with Rocha et al. (2015). It can also be observed that with the increase in base saturation, the saturation by aluminum decreased in all observed areas (Table 1).

As for the chemical attributes of the soil, the lowest fertility was observed in the FF N, represented by the lowest values of pH, Ca^{2+}, (V%) and high saturation in aluminum, with values that exceeded 90%, these results diverge from obtained by Lourente et al. (2011), who observed lower fertility in an area with degraded pasture.

Carvalho et al. (2005) noted that in areas of concentration of animals no effect on the properties f ísicas soil; however, in these areas, greater availability of nutrients is found due to the greater deposition of urine and feces, with chemical compensation and not reducing fertility.

CONCLUSIONS

The soil conditions in the reforestation at eight and seven years show that after this period, there was an improvement, mainly in the physical attributes of the soil (density and total porosity), with values that are equal to the natural conditions.

The period of six years was not enough to recover the total density and porosity of the soil.

Reforestation areas AR8 and AR7 increased soil fertility with V values above 50% in the topsoil.

LITERATURE CITED

ALONSO, J.M; LELES, P.S.S.; FERREIRA, L.N.; OLIVEIRA, N.S.A. Aporte de serapilheira em plantio de recomposição florestal em diferentes espaçamentos. *Ciência Florestal*. v.25, n.1, p. 1-11, 2015. DOI: https://doi.org/10.5902/1980509817439

ARAÚJO E.A., DE KER J.C., NEVES J.C.L., LANI J.L. Qualidade do solo: conceitos, indicadores e avaliação. *Revista Brasileira de Tecnologia Aplicada nas Ciências Agrárias*. v.5, n. 1, p.187-2006, 2012.

ARAÚJO, E.A.; LANI, J.L.; AMARAL, E.F.; GUERRA, A. Uso da terra e propriedades físicas e químicas de Argissolo Amarelo distrófico na Amazônia Ocidental. *Revista Brasileira de Ciência do Solo*. v.28, n.2 p.307-315, 2004. DOI; http://dx.doi.org/10.1590/S0100-06832004000200009

ASSIS, P.C.R.; STONE, L.F.; MEDEIROS, JC.; MADARI, B.E.; OLIVEIRA, J.M.; WRUCK, F.J. Atributos físicos do solo em sistema de integração lavoura-pecuária-floresta. *Revista Brasileira de Engenharia Agrícola e Ambiental*. v.19, n.4 p.309-316, 2015. DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v19n4p309-316

BALDOTTO, A.B., VIEIRA, E.M., SOUZA, D.O., BALDOTTO, L.E.B. Estoque e frações de carbono orgânico e fertilidade de solo sob floresta, agricultura e pecuária. *Revista Ceres*. v. 62, n. 3, p. 301-309, 2015

BOTELHO, S.M.; RODRIGUES, J.E.L.; VELOSO, C.A.C.; FERREIRA, E.V.O. Fertilizantes orgânicos. In: BRASIL, E.C.; CRAVO, M.S. VIÉGAS, I.J.M. editores. *Recomendações de adubação e calagem para o estado do Pará*. 1ª ed. Belém; Embrapa Amazônia Oriental. p.93-104, 2020.

BRADY, N.C., WEIL, R.R. Elementos da natureza e propriedades dos solos. 3 ed. Porto Alegre, 371 RS: Bookman, 686 p, 2013.

BRASIL, E.C.; CRAVO, M.S. Interpretação dos resultados de análises de solo. In: BRASIL, E.C.; CRAVO, M.S. VIÉGAS, I.J.M. editores. *Recomendações de adubação e calagem para o estado do Pará*. 2ª ed. Belém; Embrapa Amazônia Oriental. p.,55-60 2020.

CARVALHO, P.C.F.; ANGHINONI, I.; MORAES, A.; TREIN, C.R.; FLORES, J.P.C.; CEPIK, C.T.C.; LEVIEN, R.; LOPES, M.T.L.; BAGGIO, C.; LANG, C.R.; SULC, R.M.; PELISSARI, A. O estado da arte em integração lavoura-pecuária. In: GOTTSCHALL, C.S.; SILVA, J.L.S.; RODRIGUES, N.C. editores. *Produção animal: Mitos, pesquisa e adoção de tecnologia*. Canoas: Ulbra. p.7-44, 2005.

CARVALHO, P.E.R. Mogno Swietenia macrophylla. Embrapa: Circular Tecnica, 140. 12p. 2007.

CINTIA, R.S., LIMA, R.M.B., AZEVEDO, C.P., ROSSI, L.M.B. Andiroba (Carapa Guianensis Aubl.). Embrapa Amazonia Oriental. Documentos, 21p. 2006.

COSTANTINI, E.A.C; LORENZETTI, R. Soil Degradation Processes in the Italian Agricultural and Forest Ecosystems. *Italian Journal of Agronomy.* v.8, n.28, p. 223-242, 2013. DOI: https://doi.org/10.4081/ija.2013.e28

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária. Serviço Nacional de Levantamento e Conservação de Solos: *Caracterização dos solos da área do planalto de Belterra, município de Santarém, Estado do Pará- Belém*: [internet]. Rio de Janeiro, RJ Embrapa Amazônia Oriental, 2001[acesso em 10 fev 2017]. Disponível em: http://www.infoteca.cnptia.embrapa.br.

FERNANDES, M.M.; PEREIRA, M.G.; MAGALHÃES, L.M.S.; CRUZ, A.R.; GIÁCOMO, R.G. Aporte e decomposição de serapilheira em áreas de floresta secundária, plantio de sabiá (Mimosa caesalpiniaefolia Benth) e andiroba (Carapa guianensis Aubl.) na Flona Mário Xavier, RJ. *Ciência Florestal*. v.26, n.2 p.163-175, 2006. DOI: https://doi.org/10.5902/198050981897

FRAGOSO, R.O.; TEMPONI, L.G.; PEREIRA, D.C. GUIMARÃES, A.T.B. Recuperação de área degradada no domínio floresta estacional semidecidual sob diferentes tratamentos. *Ciência Florestal*. v.26, n.3, p.699-711, 2016. DOI: https://doi.org/10.5902/1980509824194

FRANCO, A.L.C.; SOBRAL, B. W.; SILVA, A.L.C.; WALL, D. H. Amazonian deforestation and soil biodiversity. *Conservation Biology.* v. 33, p. 590-600, 2019. DOI: https://doi.org/10.1111/cobi.13234.

GIÁCOMO, R.G.; PEREIRA, M.G.; GUARESCHI, R.F. MACHADO, D.L. Atributos químicos e físicos do solo, estoques de carbono e nitrogênio e frações húmicas em diferentes formações vegetais. *Ciência Florestal*. v.25, n.3, p.617-631, 2015. DOI: http://dx.doi.org/10.5902/1980509819613

JÚNIOR, C.A.S.; BOECHAT, C.L.; CARVALHO, L.A. Atributos químicos do solo sob conversão de floresta amazônica para diferentes sistemas na região norte do Pará, Brasil. *Bioscience Journal*. v.28, n.4, p.566-572, 2012.

KASSA, H; DONDEYNE, S; POESEN, J; FRANKL, A; NYSSEN, J. Impact of deforestation on soil fertility, soil carbon and nitrogen stocks: the case of the Gacheb catchment in the White Nile Basin, Ethiopia. *Agriculture, Ecosystems & Environment*. v. 247, p. 273-282, 2017. DOI: https://doi.org/10.1016/j.agee.2017.06.034.

LOURENTE, E.R.P.; MERCANTE, F.M.; ALOVISI, A.M.T.; GOMES, C.F.; GASPARINI, A.S.; NUNES, C.M. Atributos microbiológicos, químicos e físicos de solo sob diferentes sistemas de manejo e condições de Cerrado. *Pesquisa Agropecuária Tropical*. v.41, n.1, p.20-28, 2011. DOI: https://doi.org/10.5216/pat.v41i1.8459

MAGALHÃES, S.S.A.; WEBER, O.L.S.; SANTOS, C.H.; VALADÃO, F.C.A. Estoque de nutrientes sob diferentes sistemas de uso do solo de Colorado do Oeste-RO. *Acta Amazônica*. v.43, n.1, p.63-72, 2013. DOI: https://doi.org/10.1590/S0044-59672013000100008

MARTINS, G.C.; FERREIRA, M.M.; CURI, N.; VITORINO, A.C.T.; SILVA, M.L.N. Campos nativos e matas adjacentes da região de Humaitá (AM): atributos diferenciais dos solos. *Ciência e agrotecnologia*. v.30, n.2, p.221-227, 2006. DOI: https://doi.org/10.1590/S1413-70542006000200005

PAZ-KAGAN, T., OHANA-LEVI, N., HERRMANN, I., ZAADY, E., HENKIN, Z., KARNIELI, A. Catena Grazing intensity effects on soil quality: A spatial analysis of a Mediterranean grassland. *Catena* 146, 100–110, 2016.

POÇA, R.R. (2012). Indicadores químico, físico e etnopedológico de qualidade do solo em áreas em recuperação na Amazônia Oriental [Dissertação]. Belém: Universidade Federal do Pará.

REICHERT, J.M.; REINERT, D.J. BRAIDA, J.Á. Qualidade dos solos e sustentabilidade dos sistemas agrícolas. *Ciência Ambiental*. v.27, p.29-48, 2003.

Reichert, J.M.; Suzuki, L.E.A.S.; Reinert, D.J. Compactação do solo em sistemas agropecuários e florestais: identificação, efeitos, limites críticos e mitigação. Tópicos em Ciência do Solo. v.5, p.49-137, 2007.

REINERT, D.J.; REICHERT, J.M. (2006). Propriedades Físicas do Solo. Santa Maria: Universidade Federal de Santa Maria.

ROCHA, J.F.G. (2014). Solos da Região Sudeste do Município de Santarém, Estado do Pará: Mapeamento e Classificação. [Dissertação]. Santarém: Universidade Federal do Oeste do Pará.

ROCHA, J.H.T.; SANTOS, A.J.M.; DIOGO, F.A.; BACKES, C.; MELO, A.G.C., BORELLI, K.; GODINHO, T.O. Reflorestamento e recuperação de atributos químicos e físicos do solo. *Floresta e Ambiente*. v.22, n.3, p.299-306, 2015. DOI: https://doi.org/10.1590/2179-8087.041613

ROSENDO, J.S.; ROSA, R. Comparação do estoque de C estimado em pastagens e vegeteção nativa do Cerrado. *Sociedade & Natureza*. v.24, n.2, p.359-376, 2012. DOI: https://doi.org/10.1590/S1982-45132012000200014

SILVA, A.R.; SALES, A.; VELOSO, C.A.C. Atributos físicos e disponibilidade de carbono do solo em sistemas de integração lavoura-pecuária-floresta (iLPF), Homogênio em Santa Fé, no estado do Pará, Brasil. *Revista Agrotecnologia*. v.37, p.96-104, 2016.

SILVA, E.R.R.; SABLAYROLLE, M.D.G.P. Quintais agroflorestais por colonos migrantes: as plantas medicinais em Vila Nova, Mojuí dos Campos (Santarém/PA). In: Anais do VII Congresso Brasileiro de Sistemas Agroflorestais. Anais eletrônicos...Luziânia: Sociedade Brasileira de Sistemas Agroflorestais, p.4. [Acesso em 05 de jul 2016]. Disponível em: http://www.sct.embrapa.br/cdagro/tema02/02tema06.pdf.

SILVA, M.L.N.; CURI, N. Uso e conservação do solo e da água e a crise energética: reflexões e exemplos em Minas Gerais. Viçosa: Sociedade Brasileira de Ciência do Solo; 2001. (Boletim técnico, 5).

STONE, L.F.; DIDONET, A.D.; ALCÂNTARA, F. FERREIRA, E.P.B. Qualidade física de um Latossolo Vermelho ácrico sob sistemas silviagrícolas. *Revista Brasileira de Engenharia Agrícola e Ambiental*. v.19, n.10, p.953-960, 2015.

TEIXEIRA, P.C.; DONAGEMMA, G.K.; FONTANA, A.; TEIXEIRA, W.G. *Manual de métodos de análise de solos*. 3.ed. Brasília: EMBRAPA. 573p, 2017.

VELDKAMP, E.; SCHMIDT, M.; POWERS, J.S.; CORRE, M.D.. Deforestation and reforestation impacts on soils in the tropics. *Nature Reviews Earth & Environment*. v. 1, p. 590–605, 2020. DOI: 10.1038/s43017-020-0091-5.

Recebido para publicação em 29/06/2021, aprovado em 27/10/2021 e publicado em 31/12/2021.